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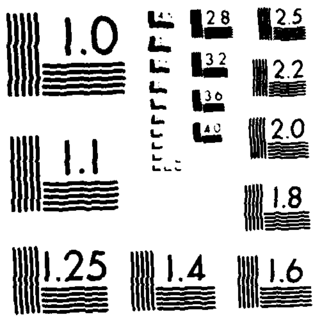

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The Role of a Mental Model in Learning to Operate a Device

David E. Kieras and Susan Bovair
University of Arizona

Technical Report No. 13 (UARZ/DP/TR-83/ONR-13)

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This report presents two studies concerned with learning how to operate a simple control panel device, and how this learning is affected by understanding the internal structure of the device, which is a device model for the device. The first experiment compared two groups, one of which learned a set of operating procedures for the device by rote, and the other learned the device model before receiving the identical procedure training.

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The model group learned the procedures faster, and even after one week, retained them better and executed them faster; a typical effect size is a 20% improvement. Furthermore, the model group could simplify, or make more efficient, the procedures far more often then the rote group. The second study examined the hypothesis that the improvement is due to the model group being able to infer the procedures, which would lead to more rapid learning and better recall performance. The same group manipulation was used, but subjects inferred the procedures rather than learning them, and "thought out loud" while doing so. The model group based their reasoning on direct inferences from the device model, and inferred the correct procedures in almost the minimum amount of time. The rote group basically followed a trial-and-error search strategy, and arrived at similarly correct procedures, but required much more effort than the model group. Thus, the benefits of having a device model are closely related to whether it supports direct and simple inference of the steps in the operating procedures.

Abstract

This report presents two studies concerned with learning how to operate a simple control panel device, and how this learning is affected by understanding the internal structure of the device, which is a <u>device model</u> for the device. The first experiment compared two groups, one of which learned a set of operating procedures for the device by rote, and the other learned the device model before receiving the identical procedure training. The model group learned the procedures faster, and even after one week, retained them better and executed them faster; a typical effect size is a 20% improvement. Furthermore, the model group could simplify, or make more efficient, the procedures far more often then the rote group. The second study examined the hypothesis that the improvement is due to the model group being able to infer the procedures, which would lead to more rapid learning and better recall performance. The same group manipulation was used, but subjects inferred the procedures rather than learning them, and "thought out loud" while doing so. The model group based their reasoning on direct inferences from the device model, and inferred the correct procedures in almost the minimum amount of time. The rote group basically followed a trial-and-error search strategy, and arrived at similarly correct procedures, but required much more effort than the model group. Thus, the benefits of having a device model are closely related to whether it supports direct and simple inference of the steps in the operating procedures.

The Role of a Mental Model in Learning to Operate a Device

David E. Kieras and Susan Bovair

University of Arizona

This report is concerned with the role of a <u>mental model</u> in learning how to operate an unfamiliar piece of equipment. By "mental model" is meant some kind of understanding of how the piece of equipment, or device, works (cf. Norman, 1982). The work in this report is concerned with having people acquire the procedures for operating a simple control panel device consisting of switches, knobs, lights, and push buttons. In this domain, the mental model consists of <u>how-it-works knowledge</u> of how the device works inside. Thus a mental model in this context is simply the user's knowledge of the internal mechanisms of the system. In the remainder of this paper this type of mental model will be termed the <u>user's device model</u>.

There has recently been considerable work on the nature of mental models (see Gentner & Stevens, 1982). This work has been mainly concerned with extremely complex physical systems, and with behavior in relatively ill-defined tasks, such as describing how an electrical circuit works. This current work has tended to emphasize mental models in which the understanding of the system approaches the level of understanding that an actual expert in the relevant technical field would have. For example, considerable attention has been devoted to how people acquire a fundamental understanding of electrical circuits, or of a complex shipboard steam propulsion system.

There are in fact two very strong intuitions about the role of a device model in learning how to operate a device, or in being able to operate it once it is learned. One is that having such knowledge would be of great value; the other, equally strong, intuition, is that it is not likely to be useful. (See Kieras & Polson, Notes 1, 2; Bond & Towne, Note 3 for more discussion). The actual practice of the technological industries suggest very strongly that such device models are in fact unnecessary. For example, the modern telephone system is in fact extremely complex, but very few people actually know how it works, even those who are otherwise highly educated. However, almost everybody can successfully operate the telephone and with minimal instruction can even place elaborate direct-dialed overseas calls. Knowledge of how the system works seems to be essentially irrelevant. Another example is the instructional material that accompanies word processing systems. Some major manufacturers of such systems have apparently adopted the policy that instructional material should focus just on how to get the job done with the system, and should not contain any how-it-works knowledge. Apparently this judgement is not badly wrong, because many people in fact learn how to operate these systems successfully within a reasonable amount of time, although many of their errors and difficulties in doing so seem to be related to the lack of this knowledge. On the other hand, it appears clear that people can infer their own device models, and in fact they do display some how-it-works knowledge for familiar devices (Kieras, Note 4). One would suppose that if these device models are badly inaccurate, people will perform very poorly in operating the device. Thus, the role of device models in operating equipment remains very unclear, despite these strong intuitions and the importance of the practical questions involved.

The hypothesis presented here is that having a model of a device will help only if this knowledge makes it possible to infer the procedures for operating the device. This knowledge can be very superficial and yet still provide this function. Thus, in learning procedures, the conceptual <u>depth</u> of the device model is nowhere near as important as the <u>relevance</u> of the model to the inference process. This marks a sharp distinction between the present approach, and the work currently being done on mental models, which tends to emphasize the depth of the understanding rather than its applicability, or relevance, to actual task situations. Thus, the investigation of the effects of how-it-works knowledge and device models on acquiring procedural knowledge has to be sensitive to the full subtleties of how such knowledge relates to the procedural knowledge being learned.

This report contains two studies. The first is a demonstration that providing a device model can be strongly facilitory. The second demonstrates that the device model can be used to infer procedures.

EXPERIMENT 1

Overview

The experiment reported here was fairly complex. In outline, the subjects learned a set of procedures for operating a simple control panel device consisting of switches and indicator lights. The goal of the procedures was to get one of the lights to flash. The <u>device model</u> group of subjects learned some how-it-works knowledge in the form of a description of the device based on the familiar television science fiction series <u>Star Trek</u>. Namely, they were taught that the device was the control panel for a "phaser bank" on the "Starship Enterprise", with the flashing light indicating a successful firing of the phaser bank. Thus the operating procedures could be explained in terms of the mechanism of this fictitious system. The <u>rote</u> group received no such instructions, but only learned the procedures "by rote". After learning the procedures, both groups were tested immediately, and after one week, for retention of the procedures.

The experiment was designed with the following goals in mind:

1. The device model information to be taught to subjects focussed on the major internal components of the system and their relationship to each other, and to the controls and indicators. Essentially, it was based on a block diagram of the internal mechanisms of the device, and this diagram was also provided to the subjects.

2. To ensure that the device model manipulation was effective, subjects not only studied the model, but also had to successfully pass a test for knowledge of the model before proceeding to the procedure training.

3. The two groups received exactly the same procedure training; this was made possible by referring to the device controls with abbreviations that could be used for both groups.

4. Since a major value of having a device model should be to facilitate learning and using the device in unusual situations, the subjects learned procedures to apply in both "normal" and "malfunction" situations.

5. Since another virtue of having a device model should be the ability to operate a device more efficiently, some of the procedures were made deliberately inefficient, and the subjects were given the opportunity to devise more efficient procedures.

Method

The Device and Device Model

A diagram of the control panel used for the device is shown in Figure 1. The user had no direct knowledge of the internal state or organization of the device; the only aspects of the device that the user was directly aware of was the settings of the switches, and whether the indicator lights were on, off, or flashing. The simplest way to explain the behavior of the device is to present the actual device model that was presented to the subjects. Figure 2 is the diagram that was shown to the subjects who learned the device model. The reader should refer both to Figure 1 and to Figure 2 while reading the following description. The toggle switch labelled SP (Shipboard Power) is the on/off switch. If the SP switch is on, the pilot light, the SP indicator, lights. The power flows into an energy booster (EB), which if operating correctly and receiving power, lights the EB Indicator. Power flows out of the energy booster into two accumulators, labelled MA (main accumulator) and SA (secondary accumulator). The rotary switch ESS (energy source selector) selects which accumulator is to be connected to the PB (phaser bank). If the corresponding pushbutton is pressed, energy flows from the accumulator to the phaser bank. Notice that the main accumulator has an indicator (MAI) which shows that the accumulator is receiving energy and functioning properly. The secondary accumulator has no such indicator; consequently, its internal condition is not indicated to the user. When the phaser bank receives the energy, the indicator labelled PFI (phaser

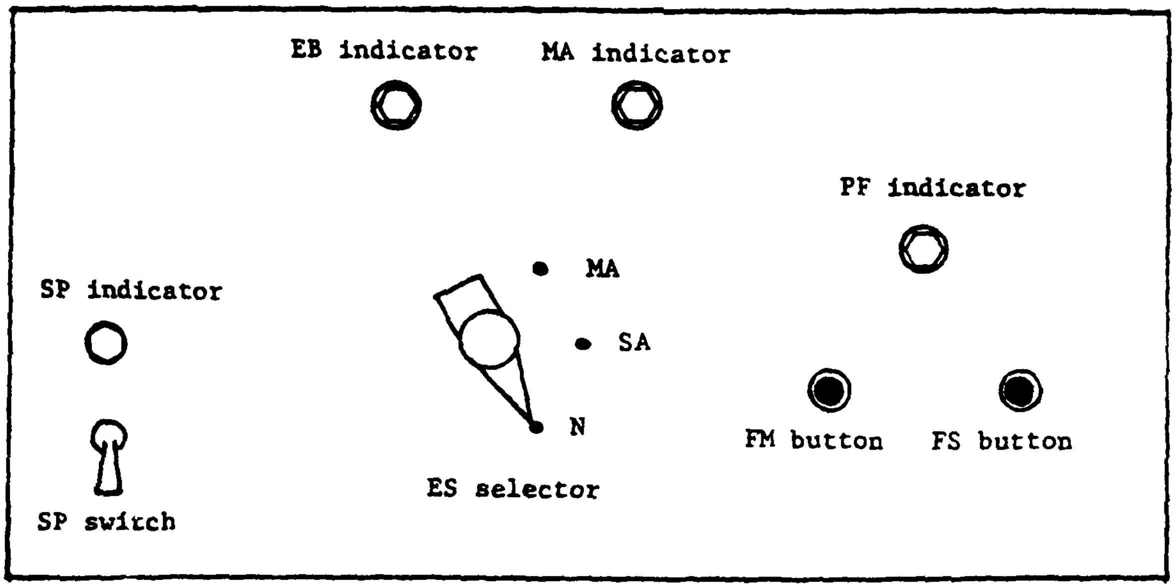

Figure 1. Sketch of the control panel of the device.

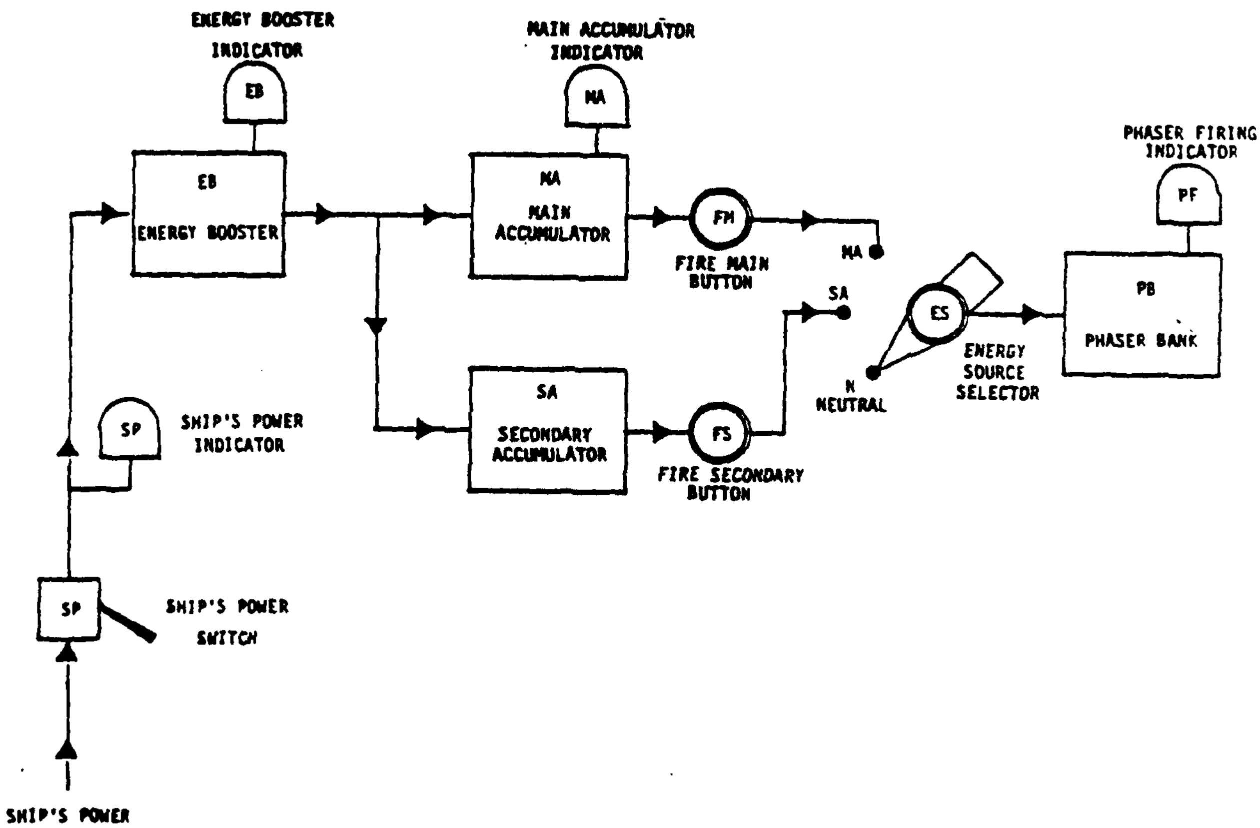

Figure 2. The block diagram representation of the device model.

firing indicator) flashes 4 times at roughly half second intervals, and then stops.

The "standard operating procedure" for the device is to turn on the SP switch, select either the MA or SA with the ESS knob, press the corresponding FM or FS button, wait for the PFI to finish flashing, then return the ESS to the N position, and turn SP off. The device is then in its standard initial state.

The key features of the device model training was that first of all, it was based on a simple description of the major components in Figure 1, along with a description of how these components related to each other, and how the controls controlled the flow of "energy" from one component to another. The training did not attempt to explain how each of the components worked, except to point out that they sometimes malfunctioned. Appendix A contains the exact device model description used, with the computer-assisted instruction details edited out for easy reading. After studying the description of the device model, subjects in the device model group were given a multiple choice test over the major concepts that the materials presented. These questions were intended to determine whether the subject understood the relationships between the major components described in the device model description. These questions are presented in full in Appendix B.

Apparatus. The device itself was simulated by means of a laboratory computer, which monitored the settings of the switches and push buttons and controlled the indicator lights accordingly. All instructions and commands to the subjects were presented on a standard video terminal positioned next to the device. A computer-assisted instruction facility was used to present all of the device model training, the procedure training, and the tests for retention of procedures. The subject was seated in a small room at a table with the terminal and the control panel, and were observed by means of a closed circuit television.

The Operating Procedures. The subjects learned two kinds of procedures for operating the device, "normal" and "malfunction" procedures. There were two normal procedures for operating the device, which were designated simply as Procedure 1 and Procedure 2. For the subjects with the device model, these two procedures corresponded to the two different accumulators of the phaser bank system that could be used to supply energy to fire the phasers. Of course, for the subjects without the model, these two procedures for getting the PFI light to flash were distinquished only by the different control actions involved. After learning these two normal procedures, the subjects were then told that sometimes the device "malfunctioned", and when this happened, it could be made to work sometimes by following an alternative procedure. These malfunction situations were then of two types; in one type, the PFI could be made to flash by means of an alternate procedure; in the other type, the PFI could not be made to flash, and the subject was to follow a procedure to indicate that an irrecoverable malfunction had occurred. This consisted of typing the letter "E" on the terminal keyboard, and then setting the ES selector to N and turning the SP switch off.

For the subjects with the device model, the malfunction concept was explained in terms of the idea that the internal components sometimes failed, but since there was some redundancy in the system, it was still possible to fire the phasers under certain conditions. If this could not be done, the Engineering section of the starship should be informed, and the system shut down. The subjects who did not have the device model were told that the goal was to get the PFI light to flash, and that sometimes the device did not work correctly, meaning that Procedure 1 and Procedure 2 would not function properly. In this case they were to use an alternate procedure to get the PFI to flash, or recognize when it could not be made to flash and indicate that an "Error condition" was present. For each normal procedure, four different malfunctions situations were defined, each of which had to be dealt with by its own procedure. This gave a total of 10 procedures for the subject to learn, one for each of the 10 situations, both normal and malfunction, that were used. The last step in each procedure consisted of typing the letter "F" for "finished". Tables 1 and 2 list the procedures and situations, which are described in terms of the device model.

Some of the procedures, numbers 3, 5, 6, and 7, were designed to be inefficient so that subjects could improve on the instructed procedures. In these procedures, the subject was instructed to follow the complete normal procedure up to the point where the PF indicator was supposed to flash. However, it was possible to tell from the indicators, as soon as the power was turned on, whether the desired procedure would work at all, and steps could then be immediately taken to either try the other accumulator, or to simply shut down the system. By including such procedures, it was possible to determine whether subjects would be able to simplify, or "short-cut", the instructed procedures.

Retention Tests. After learning all 10 procedures, the subject performed three retention tests. In each test, a command to perform either Procedure 1 or Procedure 2 would appear on the subject's terminal, and he or she would then attempt to perform the designated procedure. On half of the trials, a normal situation was the case, so the normal procedure would work; on the other half, there was some malfunction situation, and the subject had to perform the appropriate malfunction procedure. There were 10 different situations, corresponding to the 10 different procedures that were trained. No feedback was given during the tests. The data recorded were which control was operated on each step of the subject's procedure, and the corresponding response latency.

A total of 16 trials were given in each test, half of them normal situations, half malfunction situations. Situations 1 and 2, corresponding to Procedures 1 and 2, were each presented four times, and each of the eight malfunction situations once. The order of presentation of the different situations was randomized

Table 1

Operating Procedures in which
Procedure 1 is Commanded

Situation:	Normal	Malfunction			
Procedure No.:	1	3	4	5	6
Status:	All OK	EB out	PB out	MA out	MA & SA out
Steps					
1	SP on	SP on	SP on	SP on	SP on
2	ES to MA	ES to MA	ES to MA	ES to MA	ES to MA
3	press FM	press FM	press FM	press FM	press FM
4	ES to N	"E"	"E"	ES to SA	ES to N
5	SP off	ES to N	ES to N	press FS	press FS
6	"F"	SP off	SP off	ES to N	"E"
7		"F"	"F"	SP off	ES to N
8				"F"	SP off
9					"F"
Shortcut					
1		SP on		SP on	SP [illegible]
2		"E"		ES to SA	ES [illegible]
3		SP off		press FS	press FS
4		"F"		ES to N	"E"
5				SP off	ES to N
6				"F"	SP off
7					"F"
8					
9					

Table 2

Operating Procedures in which
Procedure 2 is Commanded

Situation:	Normal	Malfunction			
Procedure No.:	2	7	8	9	10
Status:	All OK	EB out	MA & SA out	SA out out	SA & PB out
Steps					
1	SP on	SP on	SP on	SP on	SP on
2	ES to SA	ES to SA	ES to SA	ES to SA	ES to SA
3	press FS	press FS	press FS	press FS	press FS
4	ES to N	"E"	"E"	ES to MA	ES to MA
5	SP off	ES to N	ES to N	press FM	press FM
6	"F"	SP off	SP off	ES to N	"E"
7		"F"	"F"	SP off	ES to N
8				"F"	SP off
9					"F"
Shortcut					
1		SP on			
2		"E"			
3		SP off			
4		"F"			
5					
6					
7					
8					
9					

for each subject on each one of the tests. The first test was given immediately after completing the procedure learning, with subjects being instructed to perform the procedures exactly as they had learned them. After completing the first test, the subject took the same test again, only under instructions to try to short-cut or simplify the procedures if possible. Following the second test, the subject was sent home, with instructions to return in one week. The subject then took the very same test, with no particular instructions given with regard to short-cuts.

Subjects. Subjects were recruited through campus advertisements and they were paid $5.00 for each session. Subjects were randomly assigned to either model or rote group so that there were always approximately equal numbers of subjects in each condition. Due to apparent sex differences noted in earlier work (Kieras, Note 3), subjects were balanced by sex so that there were an equal number of males and females in each condition. Of the 40 subjects 22 were males and 18 were females. A total of 45 subjects were run. Two subjects quit the experiment early and their partial data discarded. Three other subjects' data was discarded because it was incomplete due to data recording problems. Thus, of the 45 subjects, a total of 40 yielded data for the first session, with 20 in each group.

Three of the subjects did not return for their second session, resulting in 19 subjects in the rote condition and 18 in the model condition. A one week delay was intended, but due to scheduling problems, two subjects returned ten days after the first session, while 4 returned eight days later.

Procedure. A computer-assisted instruction program on the terminal presented the experiment instructions, training materials for the device model, and training on the procedures. The device model group and the rote group received exactly the same procedure training. The only differences in what the two groups of subjects saw was that the device model group received the device model instruction at the beginning of the experiment, and a small amount of additional device model instruction before starting to learn the malfunction procedures, and had the diagram (Figure 1) posted on the wall in front of them throughout training.

Subjects were trained on the procedures in an order slightly different from their numbering; the two normal procedures, 1 and 2, were trained first, followed by the malfunction procedures. Procedure 4 was the first malfunction procedure trained, followed by Procedure 3, then Procedures 5 through 10. The process of training each procedure was basically a serial anticipation procedure, alternating with a test procedure. The process consisted of a teaching pass through the procedure, followed by a trial pass. In a teaching pass, the subject was prompted to perform each step, and could try operating a control, or responding with a "don't know" response. If the response was correct, the subject was told so, and prompted for the next step. If the response was "don't know" or incorrect, the subject was informed of the correct step, asked to carry it out, and then prompted for the next step. After performing the last step in the teaching pass, the subject entered the trial pass, and was asked to try executing the procedure from memory, without the individual step prompts. If the entire procedure was performed correctly, another trial pass was prompted. If three correct trials in a row were performed, the subject then moved on to the next procedure. If an incorrect [illegible] was made, the subject was immediately informed, and then [illegible] the teaching pass again.

After training, the diagram was removed if the subjects were in the model condition, and the subjects performed the two retention tests described above. After the second test, subjects were asked to describe the device to the experimenter; they were asked particularly for information on how they thought the device worked, and what they thought the controls did. One week later, subjects returned and did the third retention test described above. After they had completed the test, they were once again asked to describe the device.

Results

Device Model Training

Subjects in the model group took an average of 1141 secs to learn the device model; this time included reading the training material and performing the quiz to the criterion of all questions answered correctly. Due to changes in the programming, specific information on which quiz questions were answered correctly is available for only 11 subjects. The errors were concentrated on only three of the 12 questions, as shown in Table 3. The questions about the function of the ESS, the relation of FM to ESS, and the meanings of the EB and MA indicators were missed heavily. This suggests that the relation of the ESS to the other components and the nature of the internal states of the system were the difficult aspects of the device model.

Procedure Training

Training Time. An analysis of variance was performed on the total training time for each procedure in each group; the means are shown in Table 4. There were main effects of group and procedure, and an interaction between group and procedure ($ps<.01$). The main result is that subjects in the model group learned a procedure faster than the rote subjects, by an average of 76 seconds, a 28% improvement. The means in Table 4 were examined with a Tukey (a) test for unconfounded means (Linton & Gallo, 1975) at a .05 significance level to reveal the site of the effects.

In terms of the relative difficulty of the procedures within each group, an interesting pattern appears. For the rote group, Procedures 1, 4, 5, and 9 had training times similar to each other, and significantly longer than the other procedures, which were also similar to each other. This group of procedures with

Table 3

Errors made on Test Questions during Device Model Training (N=11)

Question	Number of subjects making at least one error
What does ES selector do?	6
What does it mean if EB indicator is on?	10
What does it mean if MA indicator is on?	11
No malfunctions, ES to MA, what happens if press FM?	7
What does SP indicator indicate?	9
What can you tell from PF indicator?	12

TABLE 4

Mean Training Times (secs) for each
Procedure for the Two Groups

Procedure	Model Group			Rote Group	
1	260	*	<	427	*
2	138			172	
3	206			197	
4	374	*		347	*
5	183		<	390	*
6	165			234	
7	194			173	
8	121			169	
9	137		<	380	*
10	159			207	
Mean	194			270	

Notes. * Procedure took longer to learn than other procedures for the group. Critical value for the difference is 164 sec.

< The model group was significantly faster than the rote group on the procedure.

Table 5

Mean Errors during Teaching
Phase of Training

Procedure	Model Group		Rote Group	
1	.59		1.06	
2	.12		.12	
3	.29		.29	
4	1.18		.65	
5	.41	<	2.47	*
6	.29		.59	
7	.47		.47	
8	.53		.41	
9	.06	<	2.59	*
10	.41		.65	
Mean	.44		.93	

Notes. < Groups differed significantly on this procedure.
* Procedure took longer to learn than other procedures for the group.
Critical value for difference is 1.36 errors.

relatively long times, in this sense, is indicated with the asterisks in Table 4. For the model group, Procedures 1 and 4 have similar and longer times compared to the other procedures. Thus, in terms of training, the very first procedure (1) and the first malfunction procedure (4) are relatively hard for both groups. But, as shown in the Table, the model group has shorter training time than the rote group for all but two of the procedures, but are significantly different only for Procedures 1, 5 and 9. In these cases the difference is substantial. The rote group finds Procedure 1 very hard compared to the model group, taking 64% longer to learn. Procedures 5 and 9, which both deal with first exposures to an accumulator malfunction, are harder by factors of about 2 and 3 for the rote group compared to the model group.

Errors. The mean number of errors made during the teaching phase of training are shown in Table 5. This variable shows similar effects to these found for the training time. Because errors made in the teaching phase do not require that the subject must go back through the whole teaching again (unlike errors during the trial phase), there would not necessarily be a strong relationship between teaching errors and training time. However, there is a correlation of .50 between these two variables overall, and similar main effects of group ($p<.05$), procedure ($p<.01$), and the group by procedure interaction ($p<.01$). As shown in the Table, rote subjects make about twice as many errors during the teaching as model subjects.

Comparing the means with Tukey's (a) test for unconfounded means as before showed that the pattern of errors is quite different for the two groups. In the model group, only one procedure, number 4, produced more errors then the other procedures, but not significantly so. For the rote group, Procedures 5 and 9 produce a similarly large number of errors, much more than the model group. Thus, Procedures 5 and 9, which deal with accumulator malfunctions for each of the two normal procedures, are especially difficult to master, both in terms of time and in eliminating errors.

"Don't know" Responses. The mean number of "don't know" responses on each procedure was analyzed, but is not shown. Analysis of variance shows a main effect of procedure ($p<.01$) and a group by procedure interaction ($p=.05$), but no effect of group. The number of "don't knows" drops rapidly over the first four procedures and remains low thereafter. This is a weak variable, since the use of this response by the subject is completely optional, and it was rarely used after the first few procedures, giving essentially identical rates for almost all procedures. However, it is a relatively direct indicator of how willing the subject is to guess the steps of a procedure. Applying Tukey (a) for unfounded means gives a significant difference between the two groups on Procedure 2, where there are 40% more "don't knows" for the rote subjects. Using simple t-tests for more power, the model group also produces fewer "don't know" responses on Procedures 1 and 9 as well. These results imply that the model subjects can guess more of the procedure steps than rote subjects. This appears in both the first and second procedures, and in one of the most difficult abnormal procedures as well.

Summary. During procedure training, model subjects were faster, made fewer errors, and guessed more steps than the rote subjects. Over the entire training on the 10 procedures, model subjects were an average of about 760 seconds faster than rote subjects. This can be compared with the average 1141 seconds that it took subjects to learn the device model to criterion.

For both groups, Procedure 1 takes a relatively long time to learn, but rote subjects take longer. Thus while the first procedure is relatively difficult, it is far less so for the model subjects. For both groups, Procedure 2 is rapidly learned, reflecting its similarity to Procedure 1. Procedure 5 is learned rapidly by model subjects and with relatively few errors. However, the rote subjects find this procedure much more difficult, both taking longer and making more errors, than model subjects. Procedure 9 produces a similar result. Procedures 5 and 9 both involve using both accumulators, and are the first such for each of the two normal procedures. For the rote subjects, these procedures are especially difficult, while for model subjects, they are quite straightforward. Procedures 3, 4, 6, 7, 8, and 10 do not differ for the two groups.

Retention Tests

A detailed analysis of the retention test responses was done by examining the pattern of individual steps produced on each test trial by individual subjects. The number of subjects using a particular pattern in each of the 10 situations was tallied for each of the 3 tests. For each situation, the patterns were classified into a set of categories and the frequencies of each category, for each situation, on each test, were tallied. It must be kept in mind that since some subjects failed to return for Test 3, and there were an unequal number who did so in the two groups, weighted means or proportions must be taken over the three tests.

The categories developed can be broadly divided into 2 groups: correct and incorrect. The correct category can be further subdivided into instructed and short-cut procedures. A response pattern was called a correct instructed procedure the subject used the exact procedure that had been trained for the situation. A short-cut procedure achieved the correct final outcome on the device, but excluded some of the unnecessary steps that were part of some of the instructed procedures. The optimum shortcuts procedures are shown in Tables 1 and 2; notice that these shortcuts exist for only four situations (see Tables 1 and 2). A response pattern was considered incorrect if it did not achieve the correct final outcome on the device, or involved additional, unnecessary steps beyond those originally instructed. About 1% of the patterns could not be classified due to data recording errors. For brevity, the presentation of these results is limited to the overall results for the three tests collapsed over situations. The results for individual situations are shown only for the third test.

Retention accuracy. The proportions of correct instructed and short-cut procedures in each retention test are shown in Table 6. Considering the instructed and short-cut procedures together as correct procedures, Chi-square tests comparing the distributions of correct and incorrect responses were significant ($p<.03$) for each test and for the overall distributions. Model subjects used a correct procedure in a situation more often than rote subjects (80% vs 67%, $X^2(1)=41.9$, $p<.01$). This difference can also be seen on the individual retention tests, but the greatest difference is on the second test. Here, when subjects are asked to try to short-cut the procedures, the model subjects use the instructed procedure less often than on the first test, but use short-cuts frequently, giving 80% correct responses. However, the rote subjects are correct 61% of the time, less often than on the first test. It seems that rote subjects are confused by attempting to short-cut, because their performance on the third test, where there was no request for short-cuts, is the same as on the first test. Model subjects perform about the same on all three tests, with a slight decline by the third test.

Model subjects are not only more likely to use a correct procedure, but they are also more likely to use a short-cut. Overall, model subjects short-cut 10% of the time, out of a possible 25% of the retention test trials, while rote subjects did so only 2% of the time. However, the better performance of model subjects is not only due to their more frequent use of short-cuts, but also because they use the instructed procedure more often than rote subjects.

The long-term retention as measured by Test 3 is especially important. The model subjects show a somewhat better ability to perform correctly, than do the rote subjects (.79 vs. .71, 11% improvement). More detail on Test 3 performance appears in Table 7, which shows the proportions of response patterns classified as instructed, short-cut, and total correct for each procedure situation on Test 3.

Two key points are that first, after one week, the model subjects can short-cut a procedure much more often than the rote subjects; from Table 6, this is .12 versus .04. The model subjects were short-cutting 48% of the time when it was possible, and the rote subjects only 16% of the time when it was possible. Note especially Situations 3 and 7, in Table 7, in which the EB being out implies an obvious and drastic shortcut. While there is little difference in the proportion of total correct responses, the model subjects short-cut about twice as often on this procedure as the rote subjects. The second point is that the model group is correct more often than the rote group on most procedures, but significantly so only on a few. Thus, the model helps very little in some situations (e. g., Situation 1), and in other situations, the improvement is substantial (e. g. Situation 9).

Table 6

Proportions of Retention Test Response
Patterns in each Category for each group

Category:	Instructed Procedure	Short-cut Procedure	Total Correct
Rote Group (N=994)			
Test 1	.70	0	.70
Test 2	.57	.04	.60
Test 3	.67	.04	.71
Overall	.65	.02	.67
Model Group (N=928)			
Test 1	.79	.03	.82
Test 2	.65	.15	.81
Test 3	.67	.12	.78
Overall	.70	.10	.80

Table 7

Proportions of Test 3 Responses
in each Situation in each Category

	Situations									
Category	1	2	3	4	5	6	7	8	9	10
Instructed Procedure										
Rote	.95	.87	.42	.21	.53	.37	.32	.37	.63	.63
Model	.99	.97	.06	.11	.17	.17	.06	.44	1.00	.83
Short-Cuts										
Rote	-	-	.32	-	.0	.05	.21	-	-	-
Model	-	-	.72	-	.28	.33	.56	-	-	-
Total Correct										
Rote	.95	.87	.74	.21	.53	.42	.53	.37	.63	.63
Model	.99	.97*	.78*	.11	.44	.50	.61	.44	1.00*	.83

* Group difference on situation is significant by chi-square test

Execution Times. The time to execute a procedure was measured from the appearance of the command on the terminal to the typing of the final "F" response. Table 8 presents the mean times for the three tests, averaged over all procedures, classified by whether the response pattern was a instructed, shortcut, or an incorrect procedure. Due to the substantially unequal sample sizes and unequal representation of individual subjects due to errors and optional use of shortcuts, and the empty cell for Test 1 short-cuts, a simple and conservative way to compare these times between the two groups was with multiple independent-sample *t*-tests, using a Bonferronni-inequality significance level of .006 for each of the 8 comparisons. Under this criterion, all of the means are significantly different between the two groups, except for the Test 2 short-cut times. Thus, the model subjects were able to execute the instructed procedures faster, perform short-cuts faster after one week, and even perform incorrect procedures faster as well. The typical improvement is about 20%. Notice that if the distinction between instructed and short-cut procedures is ignored, the advantage of the model group is substantial, (about 3.2 secs, or a 17% improvement) since not only are they generally faster than the rote group, but also use the quicker short-cut procedures more often.

Sources of Errors. The nature of the errors made on the retention tests was examined using the fully detailed response pattern classification collapsed over the three retention tests. Of the total of 1872 responses, approximately 26%, or 480, were classified as errors. These error frequencies were tabulated into a table classified by group, situation, and type of error. In interpreting the results, it should be kept in mind that if the subject made more than error on a trial, the pattern was classified only by the first error made on that trial. Consequently the two final categories in the table have the property that these types of errors would have been made later in the responses classified under earlier errors. The table was subjected to a three-factor log-linear analysis, which showed that all main effects and two-factor interactions were significant ($p<.01$). However, the three-factor interaction was not significant. This means that the distribution of types of errors differed for the two groups, and the two groups differed in the number of errors made in the different situations, and the situations differed in the types of errors produced. However, any one of these two-factor interactions does not have to be qualified by the level of the third factor. As already described, the model group produced many fewer errors than the rote group, and clearly the situations differed in the number of errors they produced, and clearly some error types were more common than others. The interaction of group with situation on errors is redundant with the similar information presented above for correct responses. The interaction of procedure with type of error is basically uninteresting, because clearly the different situations would generate different error types. Thus, of these three two-factor interactions and the main effects, only the two-factor interaction of group with type of error will be discussed. Table 9, which is collapsed over situations, and shows the percentage of errors

Table 8

Mean Procedure Execution Times (secs) for each Category of Response Pattern

	Instructed Procedure	Short-cut Procedure	Incorrect
Rote Group			
Test 1	21.6	---	29.2
Test 2	19.6	15.9	24.1
Test 3	19.2	19.0	24.5
Means	20.1	17.4	26.0
Model Group			
Test 1	18.5	---	22.0
Test 2	15.6	15.2	16.5
Test 3	16.2	14.0	19.4
Means	16.8	14.6	19.2

TABLE 9

Proportion of Errors of Each Type for Both Groups, and Overall.

TYPE	Rote (N=300)	Model (N=174)	Overall
Minor	.14	.17	.15
Other	.05	.01	.04
Wrong Button	.03	.01	.02
Both Accs.	.36	.38	.37
Fail to try other Acc.	.20	.12	.17
Fail to push first button	.05	.28	.13
Push button on wrong Acc.	.11	.02	.08
Type "E" when shouldn't	.04	.00	.02
Fail to type "E"	.04	.01	.03
Totals	1.00	1.00	1.00

produced by each group, and over both groups, for each of the error types classified.

About 15% of the errors were minor errors. Such errors were tapping the space bar before the final "F", moving the ES selector to the wrong position but moving it to the correct position before firing, typing "E" one or two steps late, and pressing the firing button twice. About 4% of the errors do not classify into the other categories.

The bulk of the errors are produced in procedures used in the malfunction situations; these are as follows: (1) using both accumulators where only one should be used; (2) failing to use both accumulators when they should be; (3) failing to push the firing button (either FM or FS); which means that the subject wrongly concludes that it is not possible to get the device to operate, and so will then later type in the "E" response showing that the device is inoperative; (4) pushing the button with the ESS on the wrong setting.

These four major error types show some interesting differences, or lack of differences, between the two groups. The error of trying both accumulators when only one should be used appears proportionately equally often in both groups. The rote group fails to try the other accumulator more often than the model group does, but the model group fails to push a button (try to fire) far more often than the rote group does. Finally the rote group is more likely to make a seriously wrong error of not having the accumulator properly selected with the ESS.

The most frequent error of trying both accumulators improperly is a very common pattern and is related to the fact that Situation 4 was done correctly only 20% or less of the time. The reason for Situation 4 having such low accuracy is that most of the subjects (90% of rote subjects, 80% of model subjects) first tried to use the main accumulator as commanded, but then tried using the secondary accumulator as well. However, since the main accumulator indicator is <u>on</u> in this situation, the failure of the system to work means that the phasers are defective. Thus, there is no point in trying the secondary accumulator. It appears that subjects generalized the various malfunction procedures into one that simply involved trying the commanded accumulator first, and then always trying the other accumulator before concluding that the device was inoperative. Thus a very large number of errors are made in Situation 4, and this one type of error is by far the most common one.

<u>Summary</u>. On many, but not all, of the procedures, the model group remembers instructed procedures more accurately, uses more efficient procedures much more often, and executes the procedures faster. This is true even after one week. However, some procedures show no effect of the device model. Furthermore, model subjects make a different pattern of errors than rote subjects, and make some types of errors more often. This rules out a general motivational explanation for the overall better retention

of the model subjects, and it also shows that the device model can actually impair some aspects of performance.

Debriefing Responses

At the end of each session, the subjects were asked to describe the control device. The protocols were analyzed to determine what kinds of statements were made by the subjects in each group concerning the device on a whole, and the individual controls and indicators. Since these responses were not collected under carefully controlled conditions, the quantitative data will not be presented. Table 10 shows the typical statements, which were made by at least 15% of the subjects in any one group and session. The rote group made some consistent statements about the device as a whole, but most such responses were idiosyncratic, such as "you could use it in a plant" or "it's a security board". In contrast, half to two-thirds of the model subjects made the typical general responses shown. The statements about individual device features (controls and indicators) were typically made by about one-quarter of the rote subjects, and one-quarter to one-half of the model subjects. This shows that more of the model subjects had and retained a clearer understanding of the function of each control than for the rote subjects, and also that they retained the device model reasonably well. But, many rote subjects had acquired a basic understanding of the relations between the controls. A good example is the power switch SP, which was recognized as such by the majority of the rote subjects.

Discussion

The first experiment shows that having a device model does improve performance on learning and retaining the operating procedures for a device. This result is significant because it is not yet been clearly documented that such effects do exist. However, the question arises as to how the device model produces these effects. Clearly the extra knowledge about the device must in some way have allowed subjects to learn the procedures faster, and then once they were learned, to be retained better. In some ways, this result is similar to that which has been obtained in a variety of learning situations in which the more "meaningful" the material is, the faster it is learned and the better it is retained. However, to say that the device has become more meaningful, by virtue of having explained how it works, does not actually answer the question of how this extra information makes the procedural information easier to learn and remember. The many ways in which the results were specific to individual aspects of the situations and the device model suggest that the effects are due to very specific properties of the model, and not its global effects.

It was claimed in the introduction that relevant how-it-works knowledge is that which can support inferences about the operating procedures for the device. This hypothesis also provides a direct explanation for why it would be easier to learn to operate the device and to remember the procedures once they are learned.

Table 10

Typical Statements about Device Controls Made by Each Group

<u>Rote Group</u>

Device as a Whole:

Device is controller, or tester
Computer controls device
Don't know what device is for

Device Features:

SP is power switch
SPI is power indicator
Indicators show malfunctions, everything works
EBI, MAI show malfunctions
PFI shows success
PFI activated by buttons
ESS-N is neutral or "off"
ESS selects different paths or circuits
ESS-MA works with FM, and ESS-SA with FS

<u>Model Group</u>

Device as a Whole:

Device is for firing phasers
Description of power flow through device

Device Features:

SP is power switch
SPI is power indicator
EBI is energy booster indicator
MAI show main accumulator working
No indicator for secondary accumulator
PFI is phaser firing indicator
PFI shows success
ESS-N is neutral or "off"
ESS selects an accumulator, energy source
ESS-MA works with FM, and ESS-SA with FS

Namely, it is an old and established principle of learning that if the learner can reconstruct the to-be-remembered information in more then one way, then learning and memory will be facilitated. Perhaps the device model in Experiment 1 simply allowed subjects to infer the procedures for operating the device much more readily than the rote subjects could, and also allowed the model group subjects to reconstruct by means of inference the operating procedures even if specific details of the direct memory of them had been forgotten. This provides a specific explanation for how making a device "meaningful" allows it to be learned and remembered better.

An obvious implication of this hypothesis is that if subjects are not asked to learn a set of procedures, but rather to infer them, the model group subjects should have a decided advantage. Experiment 2 tested this implication by using two groups as before, in which one learned the device model and the other did not, and they were asked to infer the procedures while "thinking out loud". It was expected that the subjects with the device model would be able to infer the procedures quite readily, and that the think-aloud protocol data would show that they were basing their inferences on the device model. In contrast, the rote group would be forced to rely either on very general aspects of how one operates equipment, such as the fact that it has to be turned on, or would follow some kind of trial and error procedure.

EXPERIMENT 2

Method

Subjects. Subjects were students of both sexes at the University of Arizona, recruited through campus advertisements. Subjects were paid $5.00 for participating in the experiment. Of the 11 subjects who participated, the data of one subject was discarded because the verbal report was inaudible on the recording. Of the subjects whose data was used, there were 5 subjects in each condition, making a total of 10. One subject in each condition was female. Subjects were run individually, being assigned to their conditions at random.

Instructions and procedure. The equipment and general procedure were the same as for Experiment 40. Subjects first read the instructions for the experiment from the video terminal. For the rote subjects, the instructions explained the general purpose of the experiment, allowed the subjects to become familiar with the layout of the device, and then instructed subjects on the experimental procedure. The model subjects were given the same instructions, except that before the instructions on the experimental procedure, they read the device model materials and did the quiz, as in Experiment 1.

Except for the experimental procedure, the initial instructions were very similar to Experiment 1. Small modifications in the instructions were made to ensure that subjects were given no clues about the device or procedures. The two main changes were: first, in the familiarization material in Experiment 1, the SP switch was described as being "on" when it was in the up position; this was changed so that no mention of the SP switch being "on" or "off" was made. Second, the story and quiz that were given to subjects in the model condition were carefully examined and any suggestions of a particular order in which switches should be thrown or buttons pressed were eliminated. This resulted in no changes in the wording of the quiz, and only a few minor changes in the wording of the story. Also, since subjects had to infer the operating procedures, it was important for them to have a consistent starting state for the device. An addition was made to the instructions following the familiarization with the device layout. The device was described as being in its initial or starting state when the SP switch was down and the ES selector was at N, and subjects were asked to memorize this.

The instructions told rote subjects that the goal of operating the device was to make the PF indicator flash, and that they themselves would discover the control settings that make this happen. They were told that we expected them to use trial and error to find the settings that would work. Because the purpose of the experiment was to find out what reasoning they would use to make the device work, they should "think aloud" while they were working, and we were particularly interested in their guesses, hypotheses, and the knowledge they were using to find the control settings that would work. After they had found settings that would make the PF indicator flash, they would then develop a procedure to make the PF indicator flash in as few steps as possible. They would then be given an opportunity to practice their procedure. There was also a second way to make the PF indicator flash which they would discover and practice after they had found their first way.

Instructions to the model subjects were similar to those given to the rote subjects, except that they were told that the goal of operating the device was to make the phasers fire, rather than make the PF indicator flash. The model subjects had the device diagram displayed above the device throughout the whole experiment.

After subjects had read the instructions, the experiment was begun, with all statements and activities of the subject recorded on videotape; the lab computer recorded each change of the controls on the device. The experimenter prompted the subjects with questions if necessary to encourage "thinking out loud". The subjects inferred the procedures in two phases; the first consisted of inferring the two normal situation procedures (Procedures 1 and 2 in Tables 1 and 2); the second phase consisted of inferring the malfunction situation procedures.

To begin the first phase, the subject was instructed to make the PF indicator flash. After the subject had succeeded, the procedure that he or she had used was given a name, depending on which control settings had been used. For example, a procedure using the SA setting of the ESS selector (Procedure 2 in Table 2) was given the name SA procedure. The subject then worked out a second procedure for making the PF indicator flash and practiced it. This was then given the corresponding name, for example, the MA procedure. These names for the "normal" procedures were used in the rest of the session to command the subject to attempt a particular procedure.

After they had established the two procedures for making the device work, subjects began the second phase. They were given instructions that the device would sometimes break down. Sometimes it would be possible to change the control settings and still make the PF indicator flash, but, at other times, the malfunction would mean that the PF indicator could not be made to flash. Therefore, if the device did break down, they should make the PF indicator flash, if they could, and if it could not be made to flash, they should tell the experimenter. Sometimes the device would work perfectly, and at other times there would be a malfunction. The indicator lights might be helpful to them in deciding what type of malfunction had occurred, but this would not always be true.

In the second phase of the experiment, subjects did two or more runs; in each run, there were 16 trials, in which they were asked by the experimenter (cued by the lab computer) to operate the device using either the MA or SA procedures. The device worked normally half the time, and each of the eight malfunction situations appeared once. The malfunction situations were the same as for Experiment 1, and are shown in Tables 1 and 2. The order of malfunctions was the same for every subject. In the first run, the order in which malfunctions appeared was designed to introduce the malfunctions in rough order of increasing difficulty. The first situation that the subject saw was one where the device worked normally. The first malfunction was chosen to be one where the EB and MA indicator lights were both off and the device could not work. Situations where the device could be made to function by using the control settings for the alternate procedure from the one that they were asked to do, Situations 5 and 9, appeared before the corresponding situations where the alternate method would not work, Situations 6 and 10. Normal and malfunction situations alternated, but the order of which procedure (MA or SA) was commanded was apparently random.

Subjects did a minimum of two runs; all the rote subjects did three runs, as did one of the model subjects. The other four model subjects did two runs only. For the second and third runs, the order in which the malfunctions appeared was a random order, but was the same for every subject. After one or two runs through the malfunctions, subjects were asked to be as efficient as possible in their decisions as to whether they could make the device function or not. For the model subjects, this took the form of asking the subjects to pretend that the Klingons were attacking the Enterprise, and so the phasers should be fired if it was at all possible. If there was a malfunction, or if the phasers could not be made to fire, then they should make a report to engineering on what the problem seemed to be as soon as possible. Rote subjects were simply asked to predict what they thought was going to happen, and to tell the experimenter as soon as possible if they thought there was a malfunction. During these "efficiency" runs, subjects were frequently asked by the experimenter where they thought the problem lay in the device.

The number of runs required of each subject was based on a subjective judgment by the experimenter as to whether the subjects' performance had become stable in all the situations. The criteria used to make this judgement were as follows: (a) The subject was doing the procedures correctly; if the PF indicator could be made to flash then the subject was able to do it, and if the PF indicator could not be made to flash, the subject could recognize this and tell the experimenter. (b) There was little hesitation when the subject was faced with a malfunction situation. Such hesitation was exhibited if the subject continued to experiment with various settings, or made explicit verbal statements. For 3 of the 5 rote group subjects, these criteria were judged not to be met before the subject's time ran out.

Results

Number of Actions Tried

The computer recorded every change in a switch position or button press. Each change defined an *action* made by a subject. Note that because the ESS switch requires going through the SA position going to and from the MA position, the normal MA procedure requires 2 more actions, a total of 7, than the SA procedure, which requires 5. The number of actions attempted while inferring the MA and SA procedures is shown in Table 11, which shows the mean number of actions made on each attempt for the two procedures. Both groups ended up with the same optimal procedures, but the rote group tried a very large number of actions in their first and second attempts. In contrast, the model subjects deduced the correct procedures almost exactly correctly on their first attempt. This difference in number of steps on the first attempt between the two groups is significant ($t(8)=3.75$, $p<.01$). Notice that most of the rote group discovered the SA procedure first, since it is the first setting on the ES selector switch, while the model group discovered the MA procedure first, since it corresponds to the "Main" accumulator.

The number of actions tried while inferring the procedure for each malfunction situation on each run is shown in Table 12. Because the number of runs through the malfunction situations was different for the two instruction conditions, two separate three-way analyses of variance were performed; the first analysis used the number of actions on the first and second runs, and the second analysis used the number of actions on the first and *final* (second or third) runs.

Table 11

Mean Number of Actions Tried While Inferring Normal Procedures

		Attempt		
Group	Procedure Inferred	1	2	3
Rote	MA first	14.0(1)	7.01(1)	
	SA second	10.0(1)	5.0 (1)	
	SA first	26.0(4)	5.3 (4)	5.0(1)
	MA second	9.3(4)	7.0 (2)	
Model	MA first	7.4(5)	7.0 (2)	
	SA second	5.0(5)	5.0 (1)	

Note: The numbers in parentheses are the number of subjects contributing to the mean.

Table 12

Mean Number of Actions Tried in each Run for Each Group and Situation

		RUN		
	Situation	1	2	3
ROTE GROUP				
	3	46.6	9.2	7.2
	4	21.8	14.4	12.0
	5	16.8	9.2	8.0
	6	24.2	12.0	8.2
	7	25.0	12.4	6.2
	8	18.4	10.0	7.2
	9	18.0	8.4	8.4
	10	14.0	10.2	8.0
	MEAN	23.1	10.7	8.2
MODEL GROUP				
	3	9.8	7.2	
	4	9.4	11.6	
	5	9.4	6.8	
	6	9.0	8.0	
	7	7.2	5.6	
	8	8.8	8.0	
	9	8.2	8.4	
	10	11.6	11.6	
	MEAN	9.2	8.4	

The three-way ANOVA on the first and second run data shows that there was a main effect of instructional condition ($F(1,8)=12.35$, $p<.01$). The mean number of actions for model subjects was 8.8, and for rote subjects was 16.9; thus, the rote subjects took 92% more actions than the model subjects. There was a main effect of run ($F(1,8)=24.91$, $p<.01$), with the mean number of actions on the first run being 16.1, and on the second run, 9.6. There was also a main effect of situation ($F(7,56)=2.38$, $p<.05$). All three of the two-way interactions were significant. As shown in Table 12 the decline in number of actions from Run 1 to Run 2 is small for the model group, but is substantial for the rote group ($F(1,8)=19.38$, $p<.01$). For the model group there was relatively little difference between the number of actions done in inferring the procedure for different situations, but for the rote group, the difference was substantial. This group by situation interaction was significant. ($F(7,56)=3.12$, $p<.01$). The run by situation interaction was also significant ($F(7,56)=2.68$, $p<.05$), but means only that some situations did not require as many actions on the first run relative to the second one, as did others.

The ANOVA on the first and final runs showed very similar effects to those seen for the first and second runs. There were main effects of instructional condition ($F(1,8)=9.16$, $p<.05$), run ($F(1,8)=35.98$, $p<.01$) but not of situation ($F(7,56)=2.1$, $p=.059$). The three two-way interactions are similar to those above, between condition and run ($F(1,8)=29.23$, $p<.01$), condition and situation ($F(7,56)=2.56$, $p<.05$), and run and situation ($F(7,56)=3.19$, $p<.01$). There is also the three-way interaction ($F(7,56)=2.33$, $p<.05$). Generally speaking, the overall picture is the same as with the first and second run data, but since the rote group third run is nearly identical to the model group second run, the interaction effects are perhaps more pronounced. This final similarity shows that the group differences is not associated with the efficiency of the final procedures, but rather with the efficiency of inferring the procedures.

Examination of the effects of the order in which subjects saw the situations shows that for the model subjects there is virtually no effect of order; these subjects try almost the same number of actions on the first malfunction situation on their first run as they do for the last malfunction situation on their final run. However for rote subjects, the picture is quite different. On the very first malfunction situation that they see, they try far more actions than for any other situation. They also try more actions generally on all situations for their first run than on their second or final runs.

Pushbutton Actions

One type of action is very diagnostic of the approach used by subjects while inferring the procedures; this is pushing the buttons FM and FS. The button pushes made by the subject for each situation were classified by type. Table 13 shows the proportion of responses of each type in each condition. In CORRECT responses, the SP switch was on and the button pushed was appropriate for the setting of the ES selector. In CROSS responses, the SP switch was on and the ES selector was set to the opposite accumulator for the button pushed, for example, pressing the FM button with the ES selector set to SA. In NEUTRAL responses, the SP switch was on and the ES selector was set to neutral when either one of the buttons was pressed. In OFF responses, the SP switch was off when the button was pushed with the ES selector in any position. In BOTH responses, both buttons were pressed simultaneously and the other controls were in any position. Finally, HOLD responses involved one or both of the buttons being held down while other switches were manipulated. Notice that in terms of the device model, all of these response types, except for CORRECT, are "nonsense" responses.

Log-linear analysis of the button-push type on the first two runs for each instructional condition shows that the model of best fit includes all main effects and two-way interactions (all ps<.05), but no three-way interaction. The two-way tables, expressed with proportions, are shown in Table 14. The table for the condition by button-push type interaction shows that model subjects are correct more often than rote subjects, and are incorrect less often, particularly in CROSS button pushes. The run by type interaction means that subjects more often use CORRECT button pushes on their second run then on their first, while the incorrect button pushes decline in frequency on the second run. This is particularly true for HOLD, BOTH, OFF and NEUTRAL while CROSS is reduced only slightly. The run by condition interaction shows that model subjects do not change in number of button pushes between first and second runs very much (35% reduction) compared to rote subjects (150% reduction). But when the final runs only are compared (run 2 for model subjects, run 3 for rote subjects), there is no significant difference in the distribution of responses for model and rote subjects (X^2 =4.638, p>.2, 5df). A log-linear analysis of the push-type data for the first and final runs shows a similar pattern to that described above. However, the effects are weaker, because the final runs for both instruction conditions are similar, and the first and final runs for model subjects are also similar.

Table 13

Proportions of Button-Push Type for each Run for each Group

	RUN			
	1	2	3	Total
ROTE GROUP				
Correct	.43	.65	.86	.55
Cross	.21	.20	.08	.19
Neutral	.18	.11	.05	.14
Off	.13	.04	.01	.09
Both	.05	0	0	.03
Hold	.005	0	0	.003
N	377	150	87	614
MODEL GROUP				
Correct	.85	.94		.89
Cross	.02	.01		.02
Neutral	.04	.05		.05
Off	.07	0		.04
Both	.02	0		.01
Hold	0	0		
N	115	85		200

Table 14

Interactions of Group, Run, and Button-Push Type

Button-push type	Condition: Rote (N=527)	Model (N=200)
Correct	.50	.89
Cross	.21	.02
Neutral	.16	.05
Off	.10	.04
Both	.04	.003
Hold	.003	0

Button-push type	Run: One (N=492)	Two (N=235)
Correct	.53	.76
Cross	.16	.13
Neutral	.14	.09
Off	.11	.03
Both	.04	0
Hold	.004	0

Run	Condition: Rote (N=527)	Model (N=200)
One	.71	.58
Two	.28	.43

Protocol Analysis

The subject's think-aloud protocols were transcribed, and information included on which situation the subject was working on, along with the specific control actions the subject performed while talking aloud. The first step in the analysis was to eliminate redundant or irrelevant content in the protocols. This was done by summarizing for each subject the statements that the subject made about the device or about the experimental situation. These statements were then classified into a set of major categories, and then the statements within each category were classified by content. The major categories used were (a) reason statements given by the subject for performing a specific control action, (b) hypothesis statements about the device as a whole, individual controls or indicators, or about particular malfunction situations and their causes, (c) feature statements by the model subjects made about the function of individual controls, indicators, and aspects of the device, (d) meta-statements about the device or experiment as a whole, and (e) affective statements about what the subject was feeling. Once the statements were classified by content, a tally was made of which subjects generated statements in each content category. Since some subjects are considerably more talkative than others, what was tallied was which subjects made at least one statement in each given content category. Thus if a subject made several statements with essentially the same content, that subject was only counted as having made one such statement, giving a total of 297 subject statements. For purposes of presentation here, the different types of statements were further reduced into a small number of categories. Tables 15, 16, and 17 show each statement type along with one or more examples of statements included in that type, and the number of subjects making these statements, along with the mean number of times the statements were made by these subjects. By considering both the number of subjects making statements, along with the average number of statements made by these subjects, a reasonable picture can be gained of both the amount and consistency of statements made by the two groups.

Table 15 shows the results for the reasons given for performing actions while inferring the procedures. The table is in two parts corresponding to the first phase of the procedure inference process, in which subjects inferred the MA and SA procedures, and the second phase in which they inferred the procedures for the various malfunction situations. As shown in the table, the rote group explained their actions primarily in terms of general features of the device, and some form of systematic search strategy such as working from left to right or trying all combinations. In contrast, the model group gave a large number of reasons based on the device model. A similar pattern appears with the malfunction procedures. The rote group makes many statements based on either behavioral features of the device or based on their search strategy. In contrast, the model group gave many reasons for operating controls based on malfunctions in the internal components on the device. Other features of these reasons will be returned to below.

Table 15

Mean Number of Reasons Given for Performing Actions While Inferring Procedures

Type of Reason and Examples	Group: Rote	Group: Model
MA and SA Procedures		
General Device Feature: "SP seems like an ON switch"	1.5 (2)	0
Search Strategy: "That's working left to right" "MA is only thing left"	3.0 (5)	0
Model-based: "That applies power from ship to phasers"	0	4.0 (4)
Malfunction Procedures		
Search Strategy: "Trial and error"	1.75 (4)	0
Model-based: "Main [illegible] is not working"	0	2.8 (5)
Device Behavior: "SA didn't work" "EPI is on"	2.2 (5)	1.3 (3)
Indicator Failure:	0	2.0 (3)

Note: Number in parentheses is the number of subjects contributing to the mean.

Table 16 shows the statements that contained explanations and hypotheses about properties of the device or causes of the malfunctions. These statements classify into rules, model-based explanations, features of the device, and hypotheses about causes of malfunctions. Examination of the table shows that although the rote group makes many more statements in the form of rules and in terms of specific features of the device, the model group provides a large number of explanations and hypotheses based on the device model.

Finally, Table 17 shows the meta-statements and affective statements. It is clear that certain kinds of statements are much more likely to be made by the rote group than the model group. The rote group made many more statements about the device behaving in an unreliable or arbitrary fashion, or about the experimental situation being deliberately tricky, or that the subject was confused or frustrated. In contrast, the model group often made statements that corresponded to the Star Trek fantasy underlying the device model.

Discussion

Having the device model available while inferring the procedures for operating the device produced very powerful differences in both the performance of the subjects and in the protocol data. The group with the device model available inferred the procedures for operating the device in almost the minimum amount of time possible, using almost the fewest trial actions possible to do so. They engaged in very few "nonsense" trial actions, thus making only attempts that were consistent with the device model. One of the few cases where this was not so is one subject who took nine trial actions to infer the first procedure, as opposed to the minimum of seven, which was the case the rest of the model group. This subject first tried to fire the phasers without first powering up the system, saying as he did so that he wanted to see if the accumulators still had a stored charge that could be used to fire the phaser. Thus, even when a model subject did not perform optimally, he did so on the basis of reasonable inferences from the device model. The fact that the device model was used as a basis for inferring the procedures is very clear from the reasons given for the specific trial actions that the model group used. These explanations are almost always in terms of properties of the model, in sharp contrast, to the rote group whose activities are based mainly on some type of trial and error search strategy.

An additional feature of having the device model seems to be that it allows much more consistent and coherent explanations for the properties of the device and its behavior. That is, the model group could give fairly consistent explanations for the device behavior in terms of the model, whereas the rote group had to use many more specific rules for the device behavior and had to refer more often to specific features of the device.

Table 16

Mean Number of Explanations and Hypotheses Stated About Device Properties and Causes of Malfunctions

Hypothesis Type and Examples	Group: Rote	Group: Model
<u>Rules</u>		
Correct: "If SP down, nothing will work" "If EBI off, then device won't work"	5.0 (5)	1.4 (5)
Incorrect: "If only EBI on, asked for procedure won't work, but other may" "Second in a row won't work"	1.75 (4)	0
<u>Model-based Explanations</u>		
Correct: "EBI shows if energy booster working" "Energy from accumulators is transferred to phasers"	0	11.0 (5)
Incorrect: "EBI off means energy booster not getting power from ship" "ESS to MA turns on main accumulator"	0	2.0 (4)
<u>Device Features</u>		
Correct: "SPI is power indicator" "MAI is related to MA on ESS"	3.8 (5)	1.0 (2)
Incorrect: "Indicators can malfunction"	1.5 (2)	1.3 (3)
<u>Malfunction Hypotheses</u>		
Device Features: "ESS is switched" "FS button not working"	4.7 (3)	0
Model-based: "Both accumulators are malfunctioning" "Main accumulator not getting power from booster"	0	6.4 (5)

<u>Note</u>: Number in parentheses is the number of subjects contributing to the mean.

Table 17
Mean Number of Meta Statements
and Affective Statements Made
During Experiment

Statement Type and Examples	Group: Rote	Group: Model
Device Unreliability:	2.8 (5)	1.5 (2)
"It seems totally random" "No way to tell if it'll work"		
Experimenter's Tricks:	2.3 (3)	0
"You might be tricking me" "You guys are changing the rules"		
Star Trek"	0	1.0 (4)
"Get Spock, he can figure it out"		
Subject's Confusion, Frustration:	3.0 (4)	0
"I can't understand it, I'm thoroughly confused" "At this stage, I'd throw the machine out of the window"		

Note: Number in parentheses is the number of subjects contributing to the mean.

Finally, the way in which the device model affected the subject's overall view of the situation and its affective content is striking. The group without the model entertained statistical hypotheses, such as that every other trial would work, and also that the device was unreliable, or that the experimenter was tricking them, and expressed much more confusion and frustration with the device. Perhaps the device model makes possible direct and easy inferences about operating the device, and so kept the very same behavior of the device from looking arbitrary or subtle.

There are some small features of these protocol analyses that can be pointed out. For the rote group, there is some indication that they were using a stereotyped layout schema for the control panel. Several of the rote group worked systematically from left to right. For example, the SP switch seemed to be readily recognized as a power switch. That position for the SP switch as being the left-most position may have contributed to its perception as being the power switch. One or two subjects made statements to the effect that all of the switches and controls on the device must be there for a reason, and based their search strategy on this assumption.

In terms of explaining malfunctions of the device, or apparently inconsistent behavior of the device, a surprising result was that subjects in both groups attributed defects either to the front panel parts of the device, such as the lights and switches, or to the connections between them. That is, relatively common statements were that an indicator light could be malfunctioning, that the wires interconnecting the lights and switches could be broken, or that the push buttons themselves might not be working. Thus, for the rote group, it is as if there were no internal components of the device. There is also some indication that the model group tended to believe that the internal components of the system did not malfunction; rather, the connections between these components could become defective. For example, a very common statement was one like "the main accumulator is not getting power from the booster" for explaining why the MA procedure would not work when the MAI light was off. To some extent, the analysis of the device in terms of unreliable connections, controls, and indicators appears to be isomorphic to the intended device model analysis in terms of unreliable internal components. It is interesting to speculate that in the real world, the most common failures in electrical equipment are due to causes such as broken wires, burnt-out indicators, or defective switches. Perhaps subjects were generalizing this experience to this device.

Finally, in the model group, a couple of subjects apparently had difficulty with the relationship of the ESS selector switch to the accumulators. For example, a couple of subjects appeared to believe that the selector switch was between the energy booster and the accumulators, since they made statements such as "ESS to MA turns on main accumulator" or "ESS to MA allows main to receive power from the booster". A similar confusion may underlie some of the procedures that were especially difficult for the model group in Experiment 1.

CONCLUSIONS

These studies obtained definite and strong effects of having a device model. The explanation that the task becomes more "meaningful" as a result of having a device model can be replaced with a more specific explanation, that the device model helps because it makes possible specific inferences about what the operating procedures must be. Thus, the basic principle advanced here is that in the context of learning procedures, relevant how-it-works knowledge is the knowledge about the internal workings of the system that allows the user to <u>infer</u> how to operate the device, given knowledge of the goals to be achieved and the basic operations that can be performed. If this definition of what constitutes a useful device model is adopted, several conclusions follow directly:

1. The relevant how-it-works knowledge can be very superficial and incomplete. This is because the user does not need to have full understanding of this system in order to be able to infer the procedures for operating it. Kieras and Polson (Note 2) took this idea one step further and speculated on a set of criteria that could be used to choose relevant how-it-works knowledge, based on information about the task goals and subgoals that had to be achieved with the device, and whether these task goals were already known to the user of the device, or were in fact specific to the device being learned. The basic principle is that relevant how-it-works knowledge explains the system's mechanisms that are involved in fulfilling the user's goals, but how-it-works information that does not explain how or why a goal must be accomplished is not useful. This criterion sets limits on how much, and how detailed, the information should be.

2. The device model will not always be of value; it depends on whether the user in the actual task situation both needs to infer the procedures, and also needs the information in order to be able to infer the procedures. If the device is very simple, or the procedure is well practiced, there in fact may be no need for such information.

One interesting side aspect of this principle is that there is in fact a confounding between knowledge of device models and knowledge of procedures. Full experts on using a system usually have both a considerable amount of how-it-works knowledge, and also a fully developed set of procedural knowledge. This tends to suggest that having fully developed procedures depends on having a fully developed device model. But perhaps the fully expert user does not make use of a device model except under special circumstances. Rather, procedures covering a wide range of both normal and abnormal situations will be well known to the expert user without recourse to inference from the how-it-works knowledge.

This reasoning suggests that the primary effect of having a device model will be in situations where previously learned procedural knowledge will not be of direct value. Such situations are those involved with learning a novel device, troubleshooting, operating the device to achieve novel goals, making it operate in spite of a malfunction, or devising more efficient procedures for using the device. One other use of the ability to infer the procedures would be facilitating performance after a long retention interval. If the details of the procedure have been lost, the device model provides an alternate source of information which can be used to reconstruct the procedure. The point is that unless some of these conditions are the case, there may well be no value in having the device model. This, for example, is why the user of a telephone does not need a device model of the switching network. The procedures for operating a telephone are so limited, and are so heavily driven by obvious aspects of the task, that the device model information is simply of no value.

3. Learning and using a device model may have its own pitfalls. That is, knowledge of the model may be subject to misunderstandings and distortions, like any other knowledge. Thus if the user is taught a device model, but fails to learn it correctly, performance may not be facilitated at all, or may actually be impaired. This suggests that a badly designed system, with a device model that is difficult to remember or understand, may actually be harder to learn if the device model is involved. Another possible pitfall is that a very complex system may have a device model that is so complex that there is no advantage of learning it. In short, the costs of acquiring a correct and usable device model must be reckoned into any statements about the advantages of teaching one to the user.

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APPENDIX A

Device Model Instructions

To help make the device meaningful to you, we have based it on Gene Roddenberry's "Star Trek". I will explain how the device works in terms of this fantasy. This device is a phaser-bank control from the Starship "Enterprise", and you will learn several procedures for firing the phasers. When the phasers are to be fired, the bridge will direct you to fire using a specified procedure. You will then carry out the specified procedure, and when you have completed it, you will signal the bridge.

I will explain how the phaser bank works and what the controls do. After I have given you this information, there will be a short quiz on the important points. You must answer all the questions correctly before we can go on to the actual training. If you answer a question incorrectly, I will present the information to you again, and then you will do the quiz again. We'll repeat this until you can answer all the questions correctly. You will see that there is a diagram above the control panel. This diagram shows how the phaser control system works.

The arrows on the diagram show how power flows through the system. Starting on the lower left of the diagram, you can see that power is drawn from the shipboard circuits. This power is channelled to the energy booster (EB), and from there it flows to the two accumulators (MA and SA). Power is discharged from the accumulators to the phaser bank (PB) when the phasers are fired. During training, the action of the phaser system is simulated, so that power does not actually flow through the system. This is done both to prevent accidents caused by phaser fire, and to protect the delicate components of the system from overload.

Because the components of the system can be damaged, you will learn some procedures to be performed if a component malfunctions. In order for you to use these malfunction procedures correctly and effectively, it is extremely important that you understand what each component does and how the controls work. The energy booster is an essential part of the system. Power drawn from the ship cannot be used to fire the phasers because it is not at a high enough level.

The energy booster takes in power from the ship and boosts it to the level necessary to fire the phasers. Power that has been boosted by the energy booster is fed into the two accumulators. Both accumulators store large amounts of power ready to be discharged to the phaser bank whenever the phasers are fired.

Because the accumulators handle such large amounts of power, if they are used continuously they are liable to overload and burn out. To prevent continuous use of one accumulator, this system has two: the main accumulator (MA) and the secondary accumulator (SA).

Both the main and the secondary accumulators store power received from the energy booster, and either one can be used to discharge power to the phaser bank in order to fire the phasers. When one of the phaser firing buttons is pressed, the energy flows from one of the accumulators to the phaser bank (PB).

The phaser bank can receive stored energy from either the main or the secondary accumulator. Which accumulator will send its energy to the phaser bank is controlled by the energy source selector (ES). Now that you have seen what each component does, we will learn how the controls on the panel control the operation of the components.

The power coming in from the shipboard circuits is controlled by the ship's power switch (SP). When this switch is off, no power is being drawn from the ship. When the switch is turned on, power is drawn from the ship into the energy booster. The boosted power is then fed into the accumulators. The accumulator whose energy will be discharged to the phaser banks is selected by the energy source selector (ES). While the ES selector is set to neutral (N), no energy can be discharged from either accumulator to the phaser bank.

When the ES selector is set to MA the power can be drawn from the main accumulator. When the ES selector is set to SA, then power can be drawn from the secondary accumulator. The actual discharge of energy from the selected accumulator to the phaser bank is controlled by the firing buttons, which allow energy to flow from the accumulator to the phaser bank. When the main accumulator has been selected, the phasers are fired using the fire main (FM) button. When the secondary accumulator has been selected, then the fire secondary (FS) button fires the phasers.

As the diagram shows, each accumulator has its own firing button. Thus, if the secondary accumulator has been selected with the ES selector, then the phasers can only be fired with the FS button. If the main accumulator was selected, only the FM button will fire the phasers. Finally, the control panel is provided with four indicator lights. Each indicator is attached to a particular component in the system. The indicator will only light if the component that it is attached to is both working and receiving energy.

The SP indicator will light if the phaser system is receiving power from the ship. Thus the SP indicator will light when you turn on the SP switch. The energy booster (EB) indicator will light if the energy booster is receiving power from the ship, and operating correctly and putting out the boosted energy.

The main accumulator (MA) indicator will light if the main accumulator is receiving power from the energy booster, and the main accumulator is working and storing energy.

Note that there is no indicator for the secondary accumulator. Lastly, the phaser firing (PF) indicator will light if the phasers are firing. The phasers can only fire if they are both working and getting power from the selected accumulator. Because the phasers fire in pulses, the PF indicator will flash while they are firing.

***

You have now learned two procedures for firing the phasers: Procedure 1 for firing using the main accumulator, and Procedure 2 for firing using the secondary accumulator.

You will now go on to learn what you should do if the phasers do not fire when you press the appropriate firing button. You will be taught procedures to follow in the same way as you were taught the normal procedures. If the phasers do not fire when you press the appropriate firing button, it means that one or more of the components of the phaser control system has malfunctioned. In order to determine the correct procedure, you must decide which components have failed. The indicators will provide you with valuable clues. For example, you know that the EB indicator will light up if the energy booster is both working and receiving power. If you are supplying energy, and the indicator does not light, you can deduce that the energy booster is not working. If the only malfunction is in one of the accumulators, then an obvious thing to do is to try firing from the other accumulator. If, however, either the phaser banks or the energy booster are malfunctioning, then you cannot fire the phaser, no matter what you try.

As you work through the malfunction procedures, you will find that whenever the problem appears to be with an accumulator, you will try to fire using the other accumulator. If, however, the problem is not with the accumulators, or if there is more than one malfunction, you will be taught to tap an "E" on the keyboard and then power down the phaser system. When you tap an "E", you are informing Engineering that you have a major malfunction in the phaser system. After you have set the ES selector to N and turned off ship's power with the SP switch, you will still tap "F" for finished so that the engineers know that it is safe to start working on the problem.

APPENDIX B

Test Questions on Device Model

Where does the energy booster get its power from?
(1) from the accumulators.
(2) from the shipboard power circuits.
(3) from its own special power supply.

Where does the main accumulator get its energy from?
(1) from the energy booster.
(2) directly from the shipboard circuits.
(3) from its own special power supply.

Where does the secondary accumulator get its energy from?
(1) directly from the shipboard circuits.
(2) from the main accumulator.
(3) from the energy booster.

Where does the phaser bank get its energy from?
(1) from either one of the two accumulators.
(2) from the main accumulator only.
(3) directly from the energy booster.

What is the SP switch for?
(1) It controls which accumulator will be used for firing.
(2) It controls whether the phaser system can draw power from the ship.
(3) It fires the phasers.

What does the ES selector do?
(1) It selects which accumulator the energy booster will send energy to.
(2) It selects whether energy will be received from the energy booster or not.
(3) It selects which accumulator will be used for firing the phasers.

Assume that the phaser control system is in full working order, that power is being supplied to the system, and that the ES selector is set to MA.

Now, what will happen if the FM button is pressed?
(1) The main accumulator will discharge energy to the phaser banks and the phasers will fire.
(2) The phaser bank will receive energy from the secondary accumulator and the phasers will fire.
(3) The phaser bank will receive energy directly from the energy booster and the phasers will fire.

Assume that the phaser control system is in full working order, that power is being supplied to the system and that the ES selector is set to MA.

Now, what will happen if the FS button is pressed?
(1) Nothing. The ES selector must be set to SA for the phasers

to fire when the FS button is pressed.
(2) The main accumulator will discharge power to the phaser banks and the phasers will fire.
(3) The secondary accumulator will discharge power to the phaser banks and the phasers will fire.

What does the SP indicator indicate?
(1) It indicates whether the phasers are ready to fire or not.
(2) It indicates whether or not the phaser system is receiving power from the ship.
(3) It indicates whether the shipboard power circuits are supplying full power or half power.

What does it mean if the EB indicator is on?
(1) It means that the energy booster is receiving half power from the shipboard power circuits.
(2) It means only that the energy booster is receiving power from the shipboard power circuits.
(3) It means that the energy booster is both receiving power from the shipboard circuits and is functioning properly.

What does it mean if the MA indicator is on?
(1) It means that the main accumulator is discharging power to the phasers.
(2) It means that the main accumlator is working and is receiving energy from the energy booster.
(3) It means that both accumlators are receiving energy and working properly.

What can you tell from the PF indicator?
(1) If it flashes it means that the phasers are ready to fire.
(2) If it flashes it means that the phasers are not working.
(3) If it flashes it means that the phasers are firing.

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